Reliability Based Optimization within the CAD Environment

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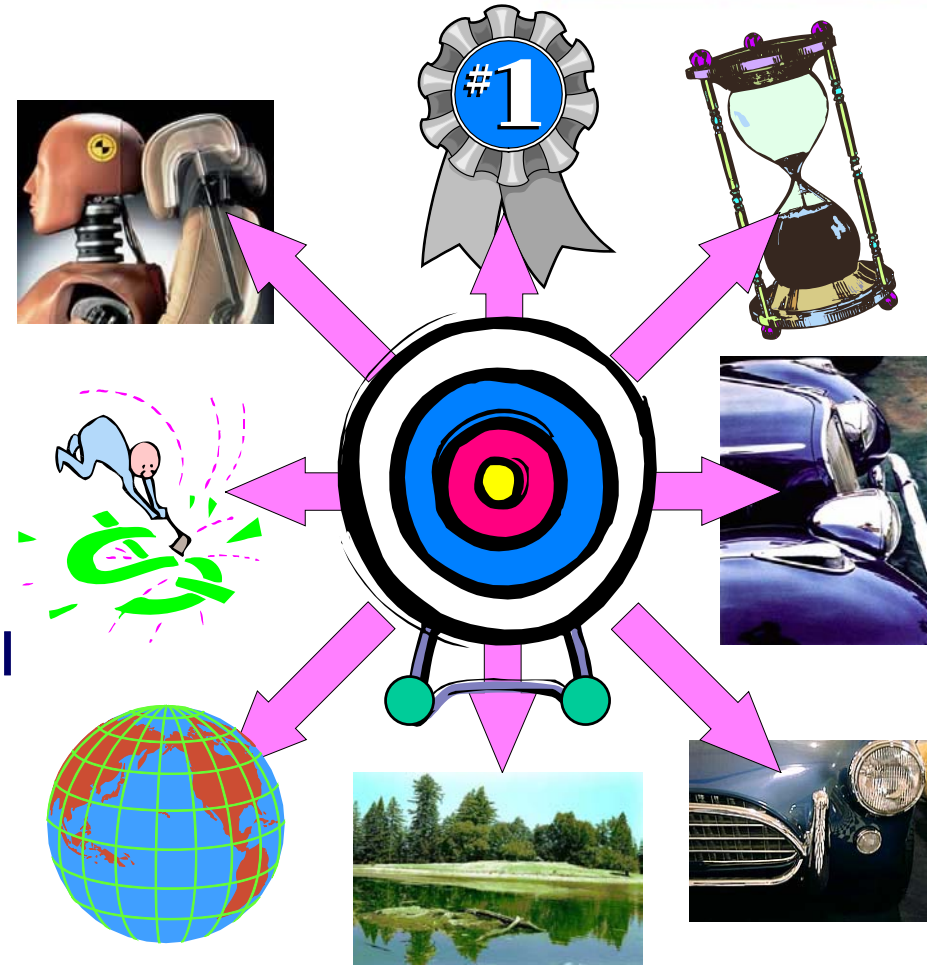
Contradicting Design Requirements

- Cost
- Performance & safety
- Quality
- Time to market & short life cycle
- Environmental impacts
- Wow Aesthetics (creating waves of lust for the product, I got to have it ...)
- Major Changes in Industry's Business Model



Changes in Automotive Industry's Business Model

- Cycle development time from concept to production is being compressed significantly
  - 1992: 60 months
  - 1996: 48 months
  - 2000: 18 months

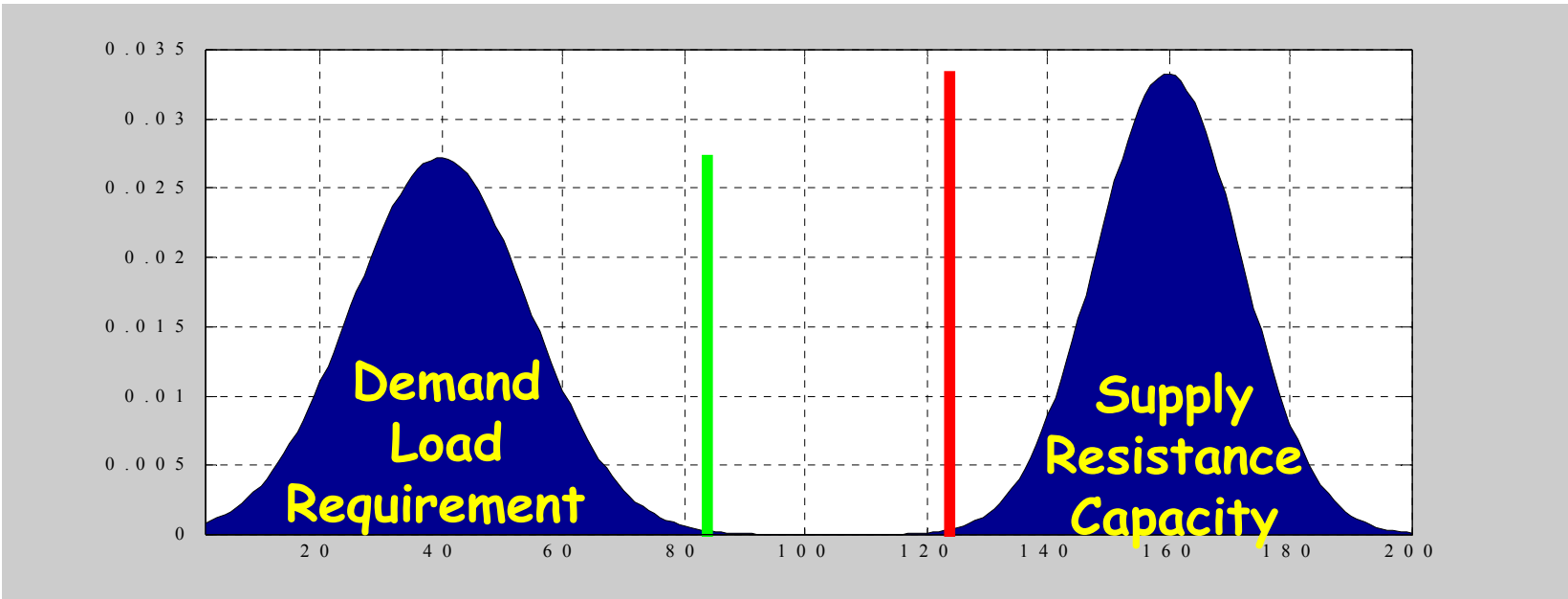
- Vehicle designs are tailored to focused markets
- Vehicles are being manufactured more on a global scale
- Vehicles designed increasingly through multiple engineering sites around the world
- Need for enabling companies throughout the supply chain and extended enterprise to share information through a web-centric visualization approach

Quality - Robust Design

- **Definition of Robust Design:**
  Deliver customer expectations at profitable cost regardless of:
  - customer usage
  - variation in manufacturing
  - variation in supplier
  - variation in distribution, delivery & installation
  - degradation over product life
- **Goals of Robust Design (shift and squeeze)**
  - Shift performance mean to the target value
  - Reduce product's performance variability

Traditional Deterministic Approach

- Accounts for uncertainties through the use of empirical Safety factors:
  - Are derived based on past experience
  - Do not guarantee safety or satisfactory performance
  - Do not provide sufficient information to achieve optimal use of available resources



Statistical Design Performance Simulation

" Product quality requires managerial, technological and statistical concepts throughout all the major functions of the organization …"

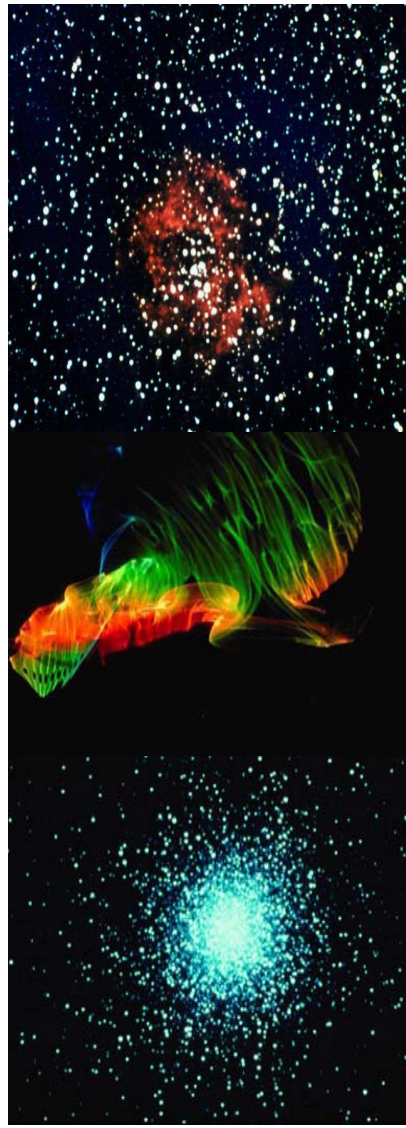
Josheph M. Juran

Variation (thickness, properties, surface finish, loads, etc.) is … ***THE ENEMY***

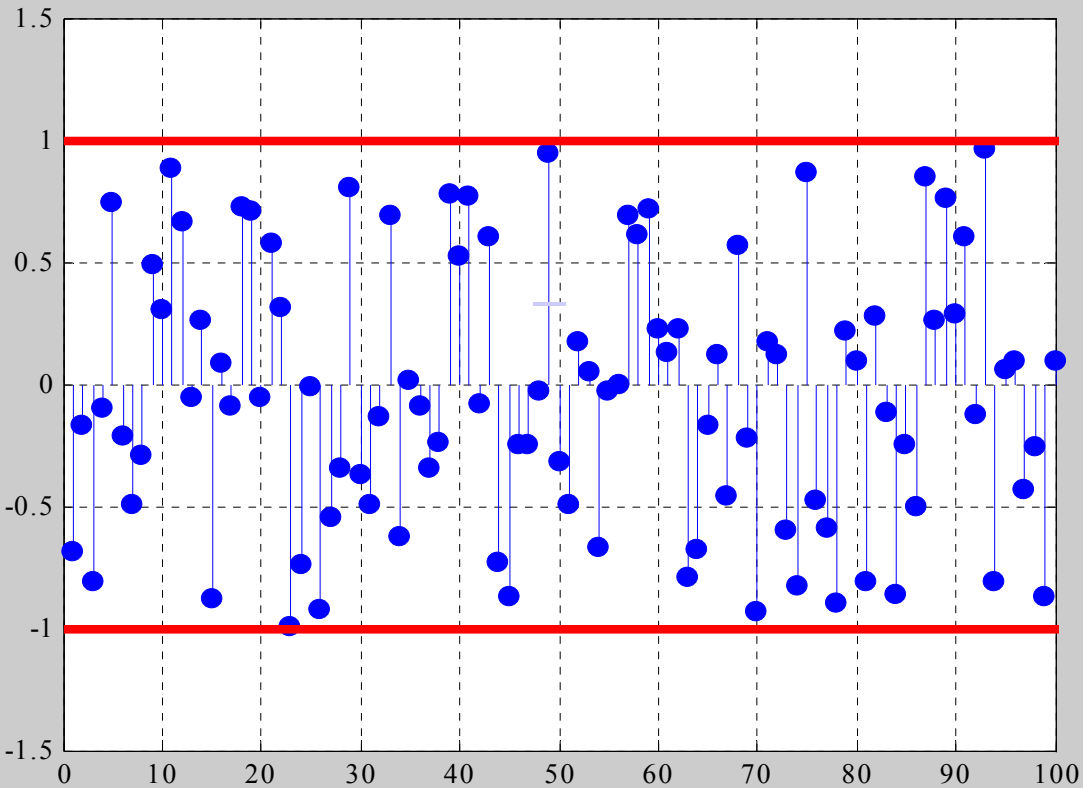
DOE, Six Sigma, Statistical FEA, Behavioral Modeling … ***THE DEFENCE***

Tools for Robust Design

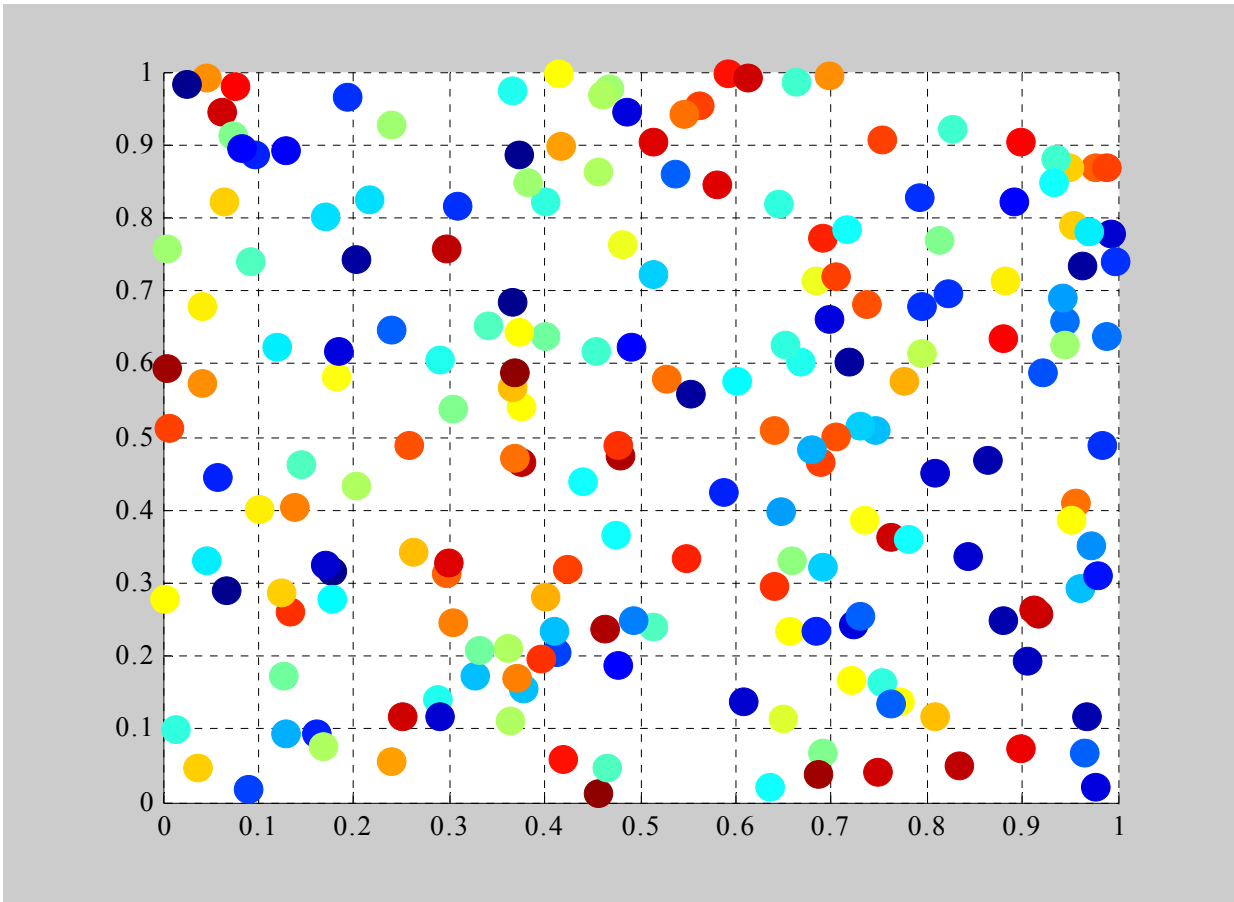
- Design Of Experiments (DOE)
  - Exploits nonlinearities and interactions between noise & control parameters to reduce product performance variability
  - full factorial, fractional factorial, Monte-Carlo, LHC
- Response Surface Methods
  - Central Composite Design
  - Box-Behnken Design
- 6-sigma design (Statistical Performance)
  - Identifying & qualifying causes of variation
  - Centering performance on specification target
  - Achieving Six Sigma level robustness on the key product performance characteristics with respect to the quantified variation



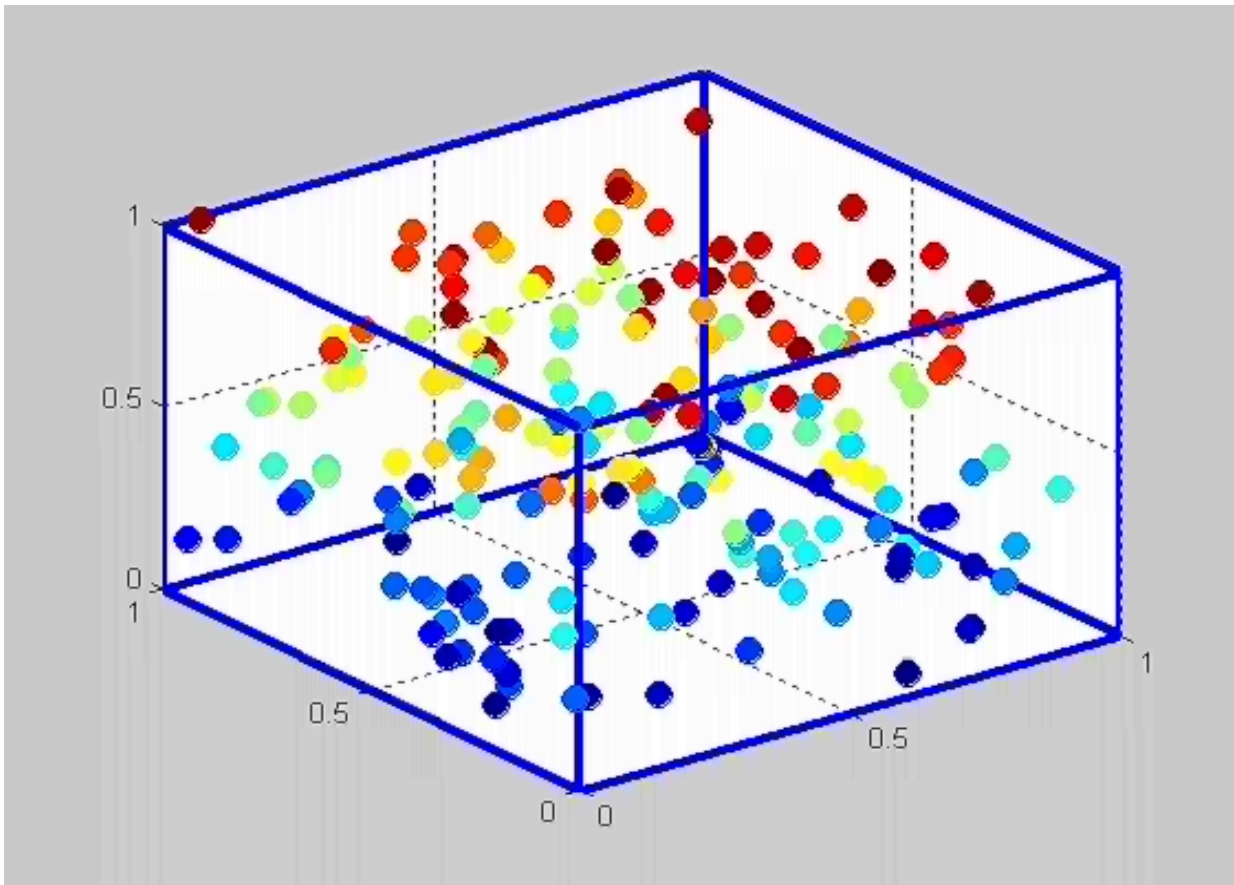
Design Space Exploration 1 Variable



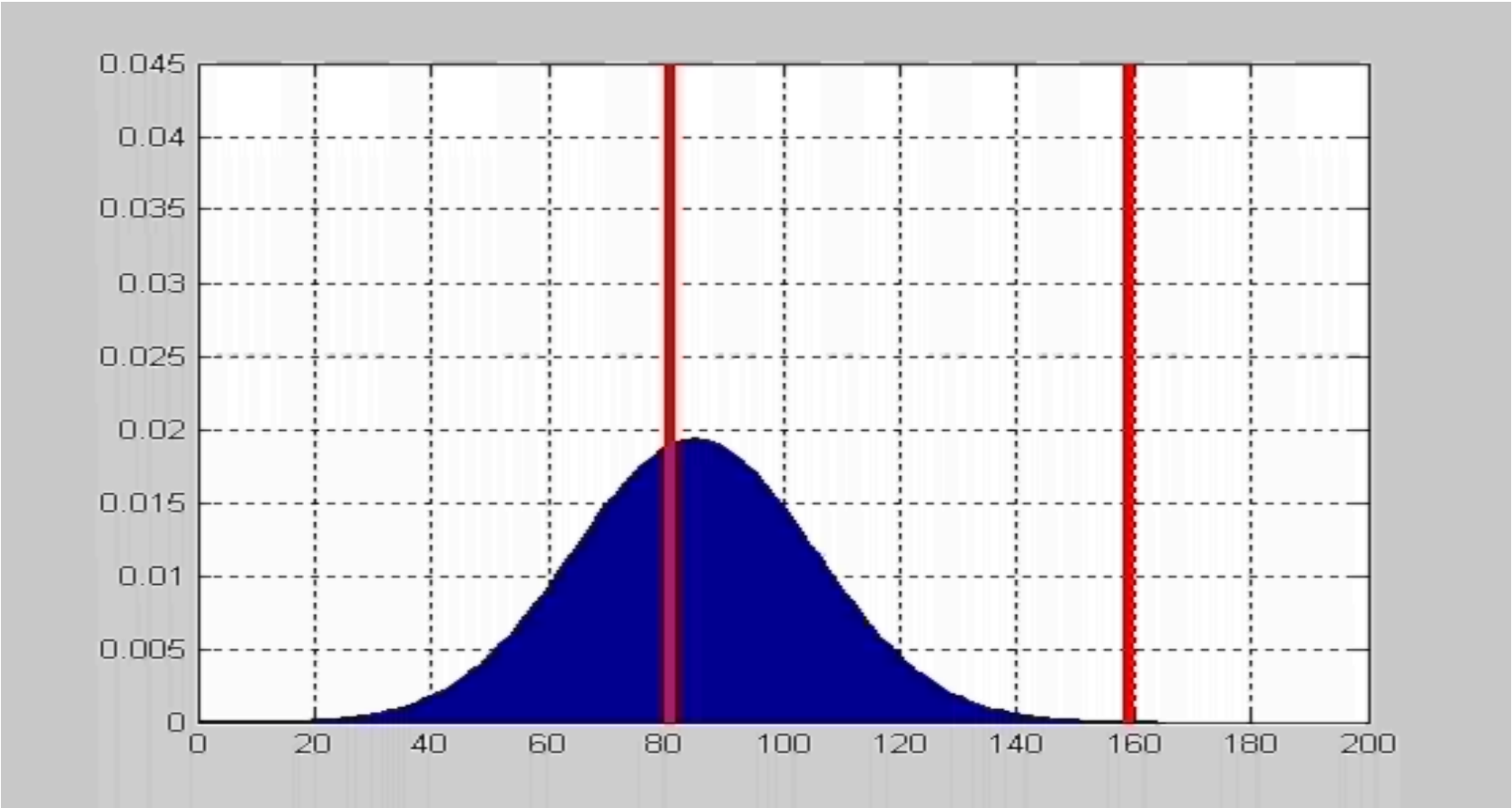
Design Space Exploration 2 Variables



Design Space Exploration 3 Variables



Statistical Performance: Shift and Squeeze



Improved Quality reduced Total Cost

Cost of Defect or Failure

- Lost Customers
- Liability
- Recalls
- Rework

Examples:

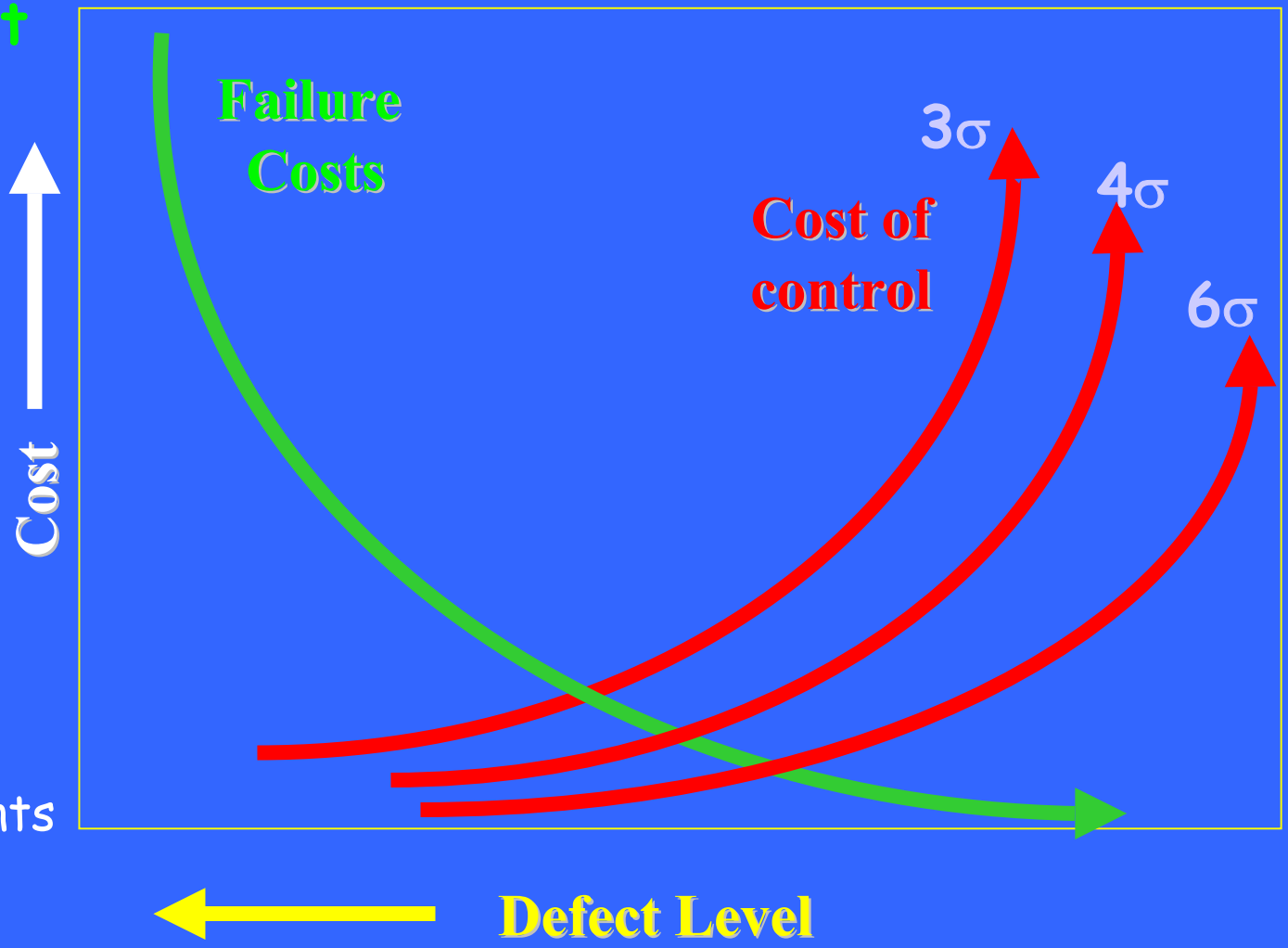
Titanic

Asbestos

Breast Implants

Bhopal, India

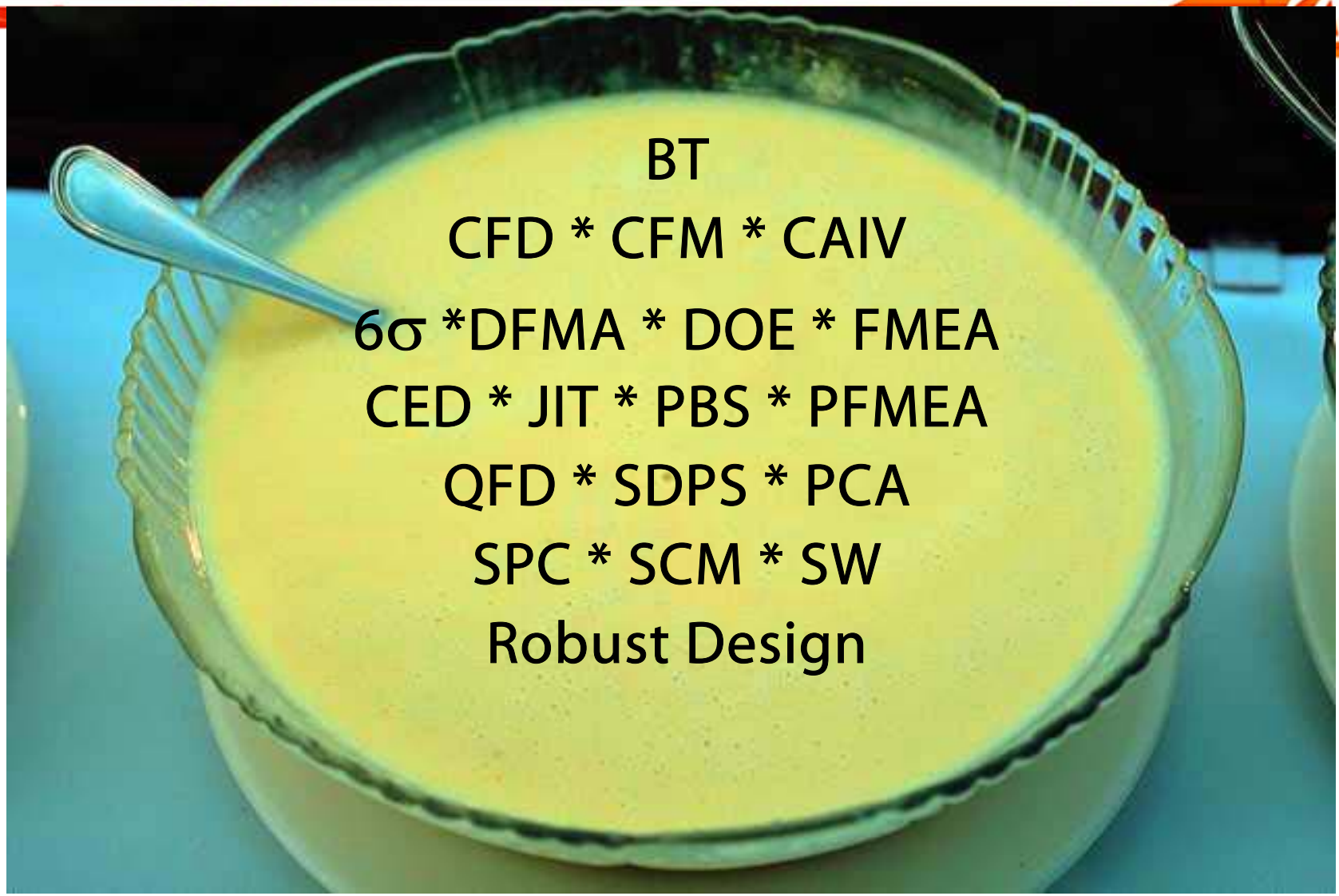
...



Elements of Quality Management Process

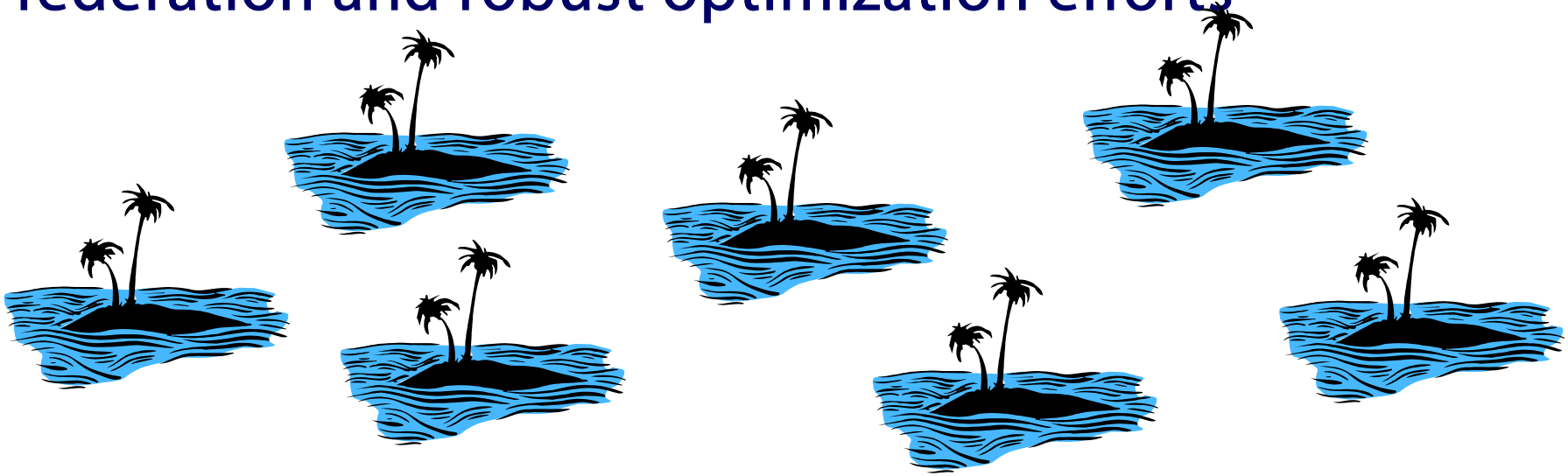
- Agile Improvement Process
- Axiomatic Design
- Benchmarking & Bench-trending
- Catch-ball
- Cellular Manufacturing
- Continuous Flow Development
- Continuous Flow Manufacturing
- Cycle Time Management
- Defect Reduction
- Design for Manufacturing and Assembly
- Design of Experiments
- Failure Modes effects Analysis
- Cause and Effect Diagrams
- Just In Time
- Performance Based Specifications
- Process Failure Mode Effects Analysis
- Quality Function Deployment
- Robust Design
- Self-Directed Work Teams
- Statistical Design Performance Simulation
- Process Capability Analysis
- Statistical Process Control
- Supply Chain Management
- Synchronous Workshops
- Theory of Constraints
- Thinking Process Reality Trees
- Total Productive Maintenance

Elements of Quality Process: The alphabet soup



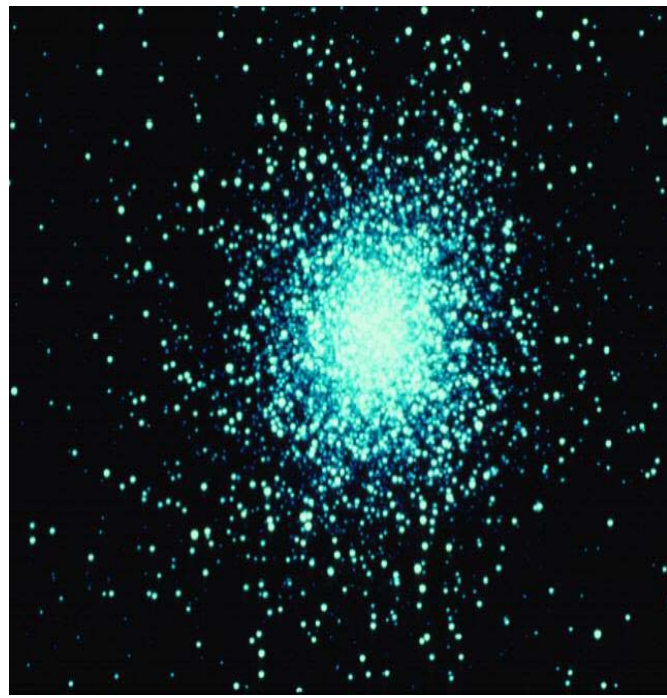
Elements of Quality Management Process

- Although all the elements of quality management process are closely connected they remain apart because they have been developed independently from each other
- Integration of these tools is critical to the organization and necessary for successful federation and robust optimization efforts

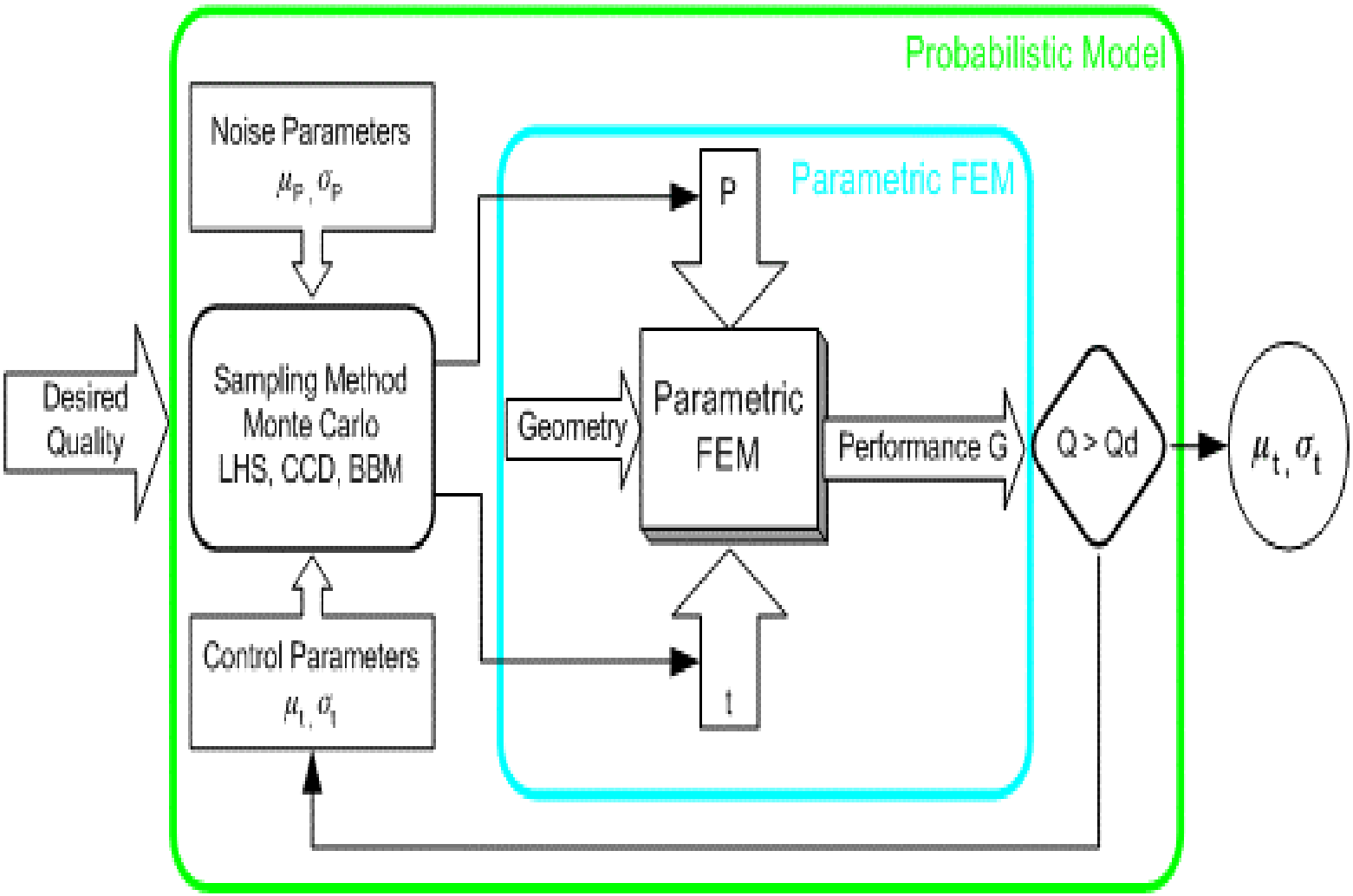


Identifying Noise & Control Parameters

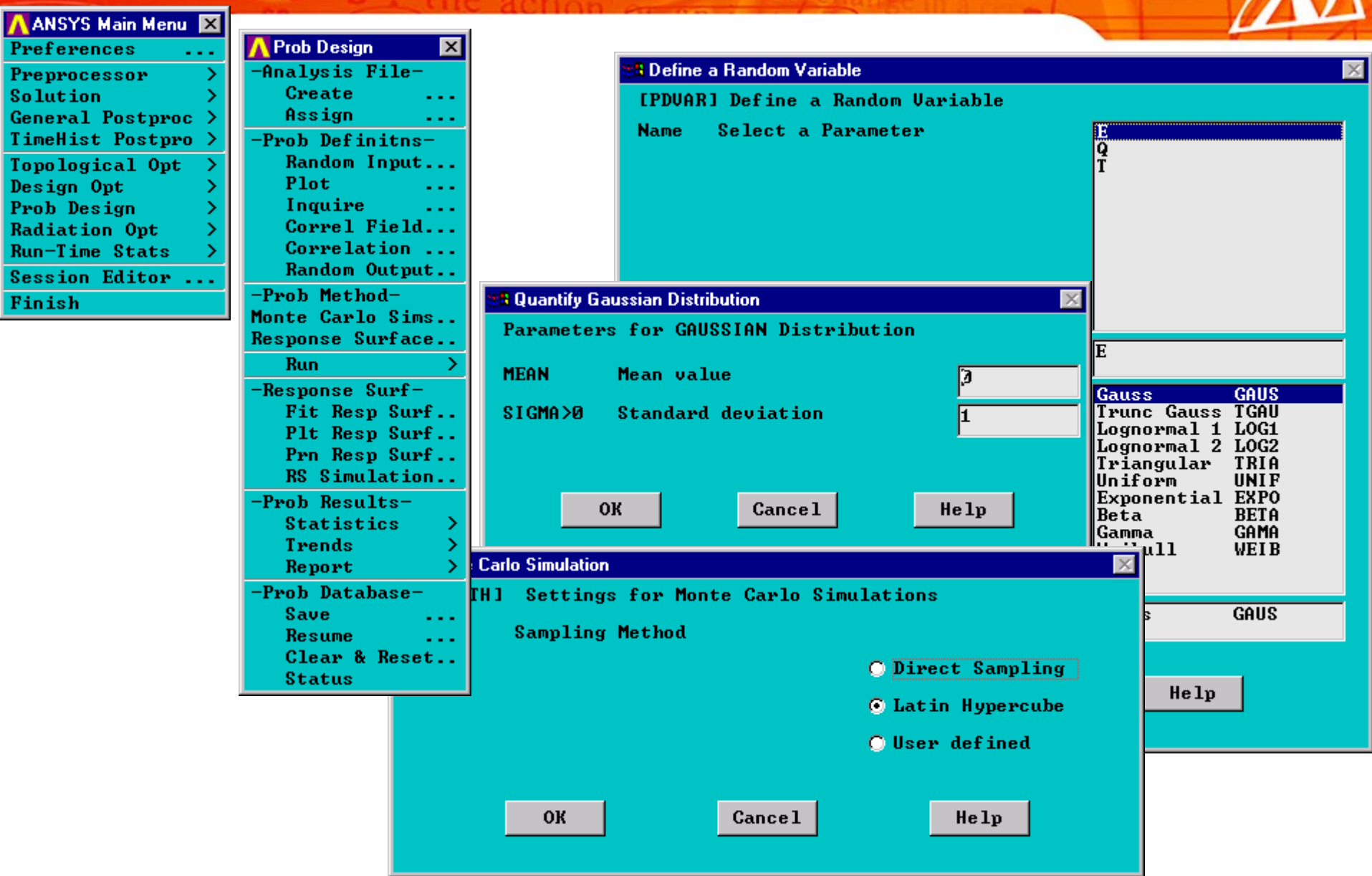
- **Noise parameters:**
  Factors that are beyond the control of the designer
  - material property variability
  - manufacturing process limitations
  - environment temperature & humidity
  - component degradation with time
  - …
- **Control Parameters:**
  Factors that the designer can control
  - geometric design variables
  - material selections
  - design configurations
  - manufacturing process settings
  - …



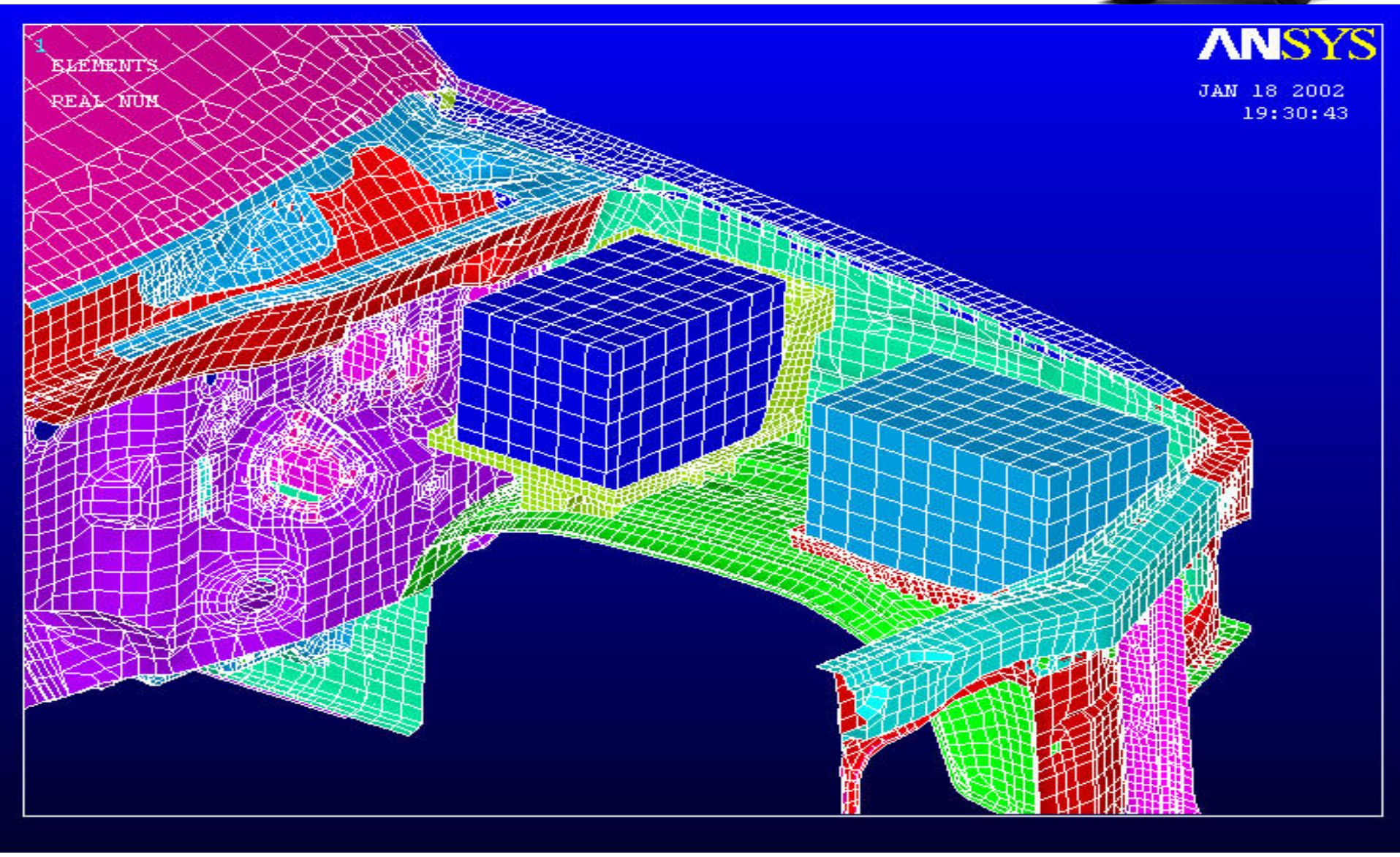
Workflow for Probabilistic Design System



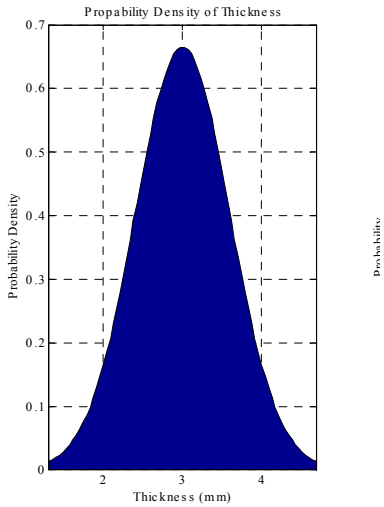
Probabilistic Analysis setup within ANSYS is SIMPLE

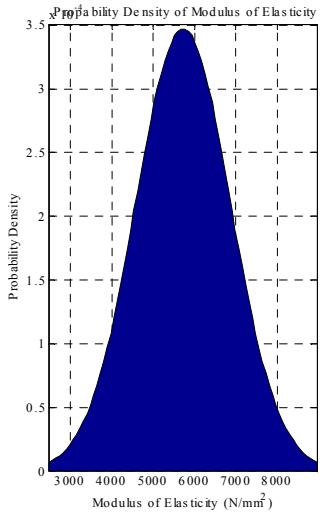


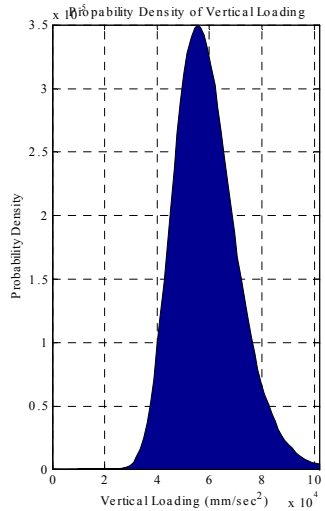
Automotive Example

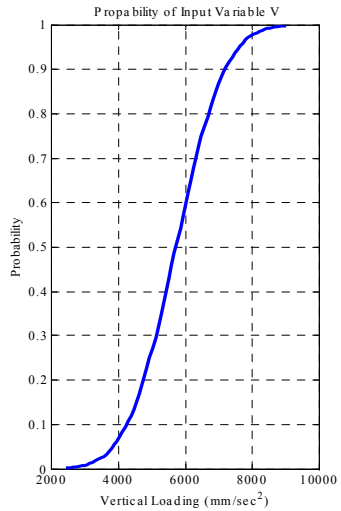


Probability Distributions of input and output variables







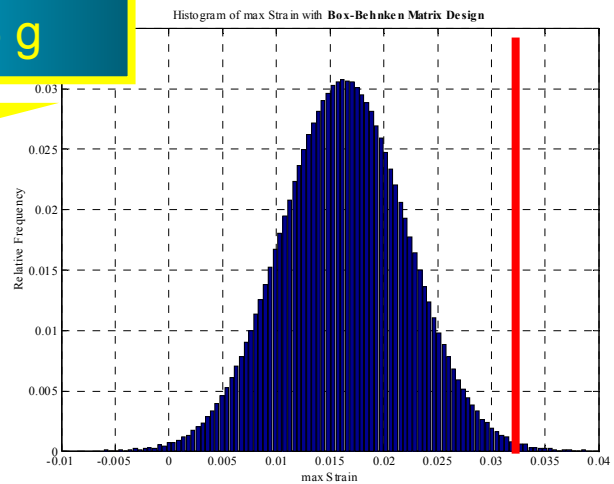


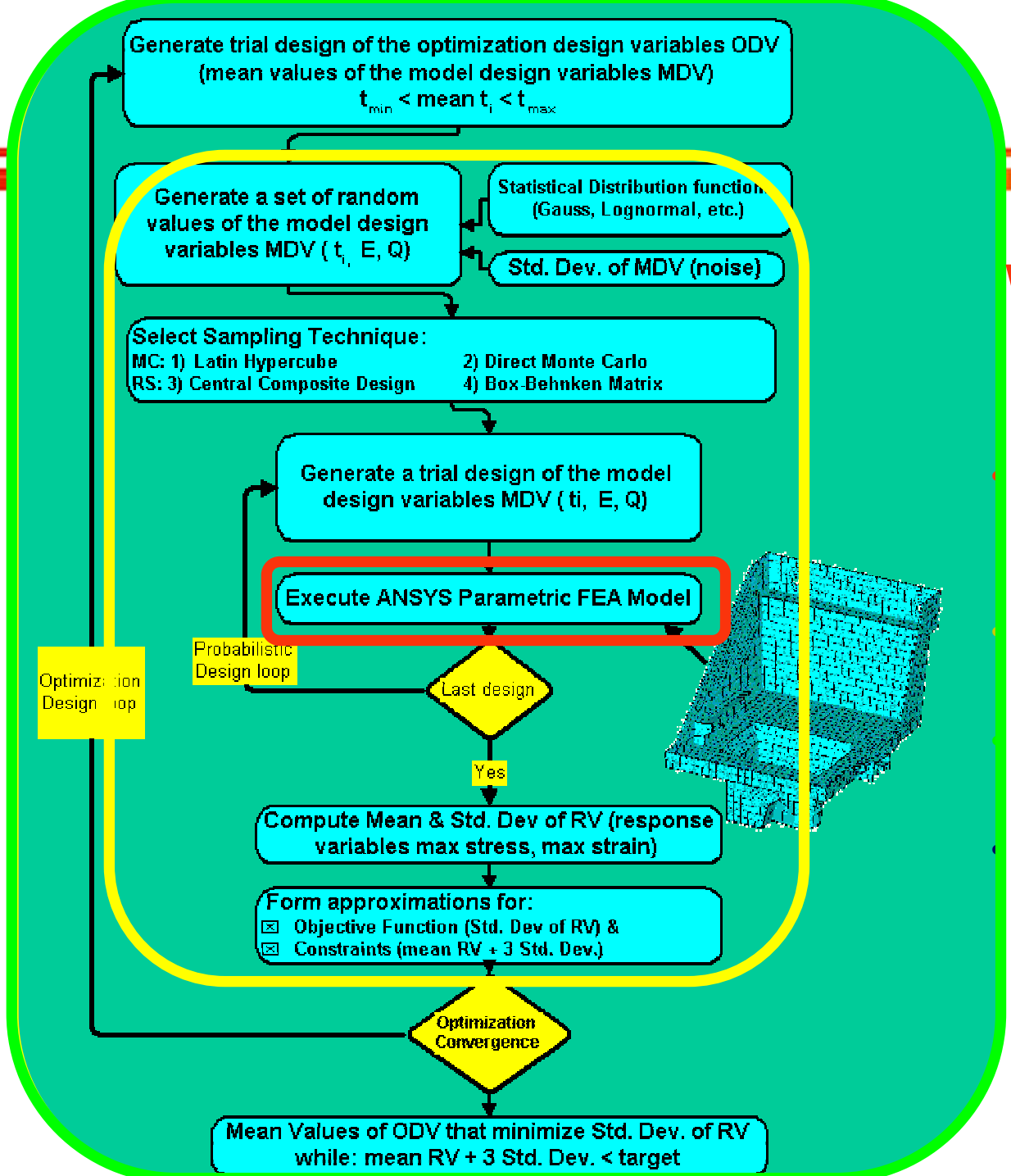
Thickness (3.8-4.2)

Modulus E

Loading 6 g

Probabilistic Design Loop





Workflow

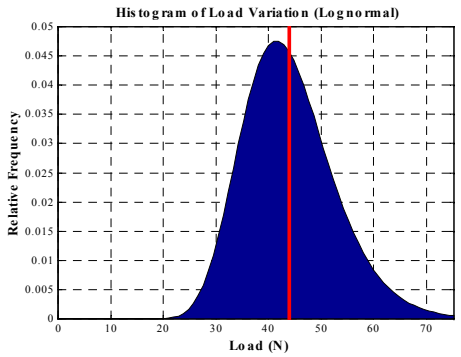
Automatic, No Manual iteration:
CAD -> Meshing -> FEA

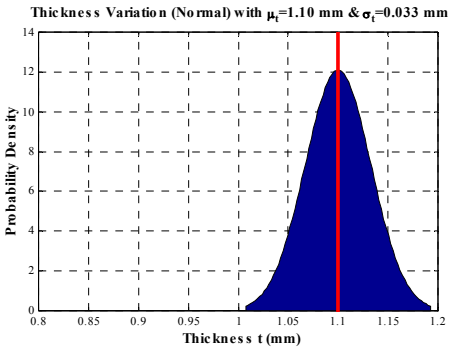
Probabilistic Design Loop

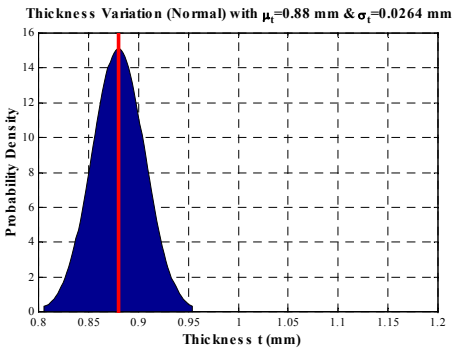
Optimization Loop with reliability constraints

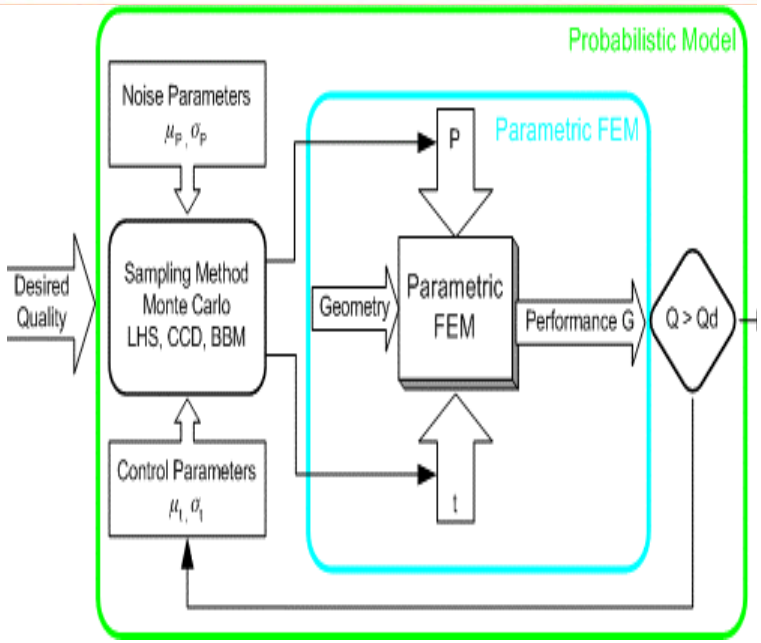
Deterministic Optimum designs could lead to unreliable or even catastrophic designs

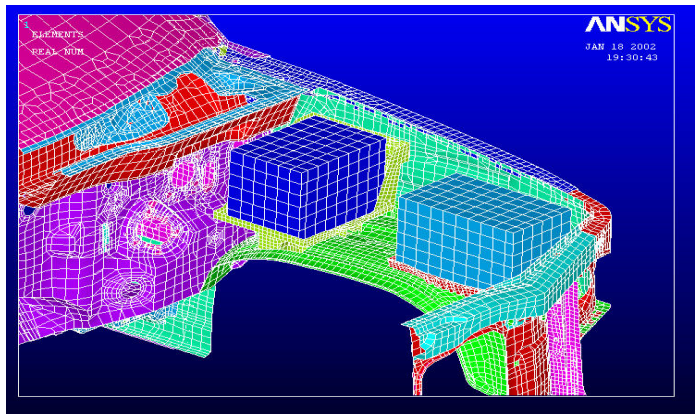
Workflow for Robust Design System



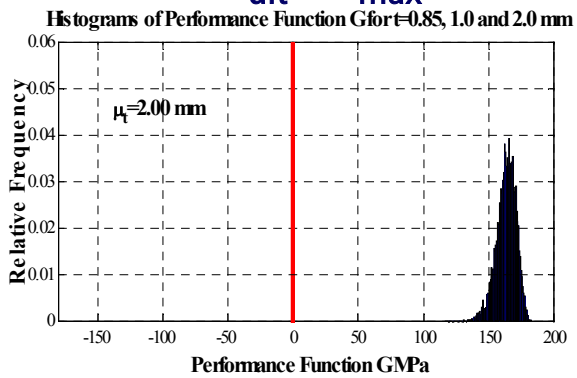


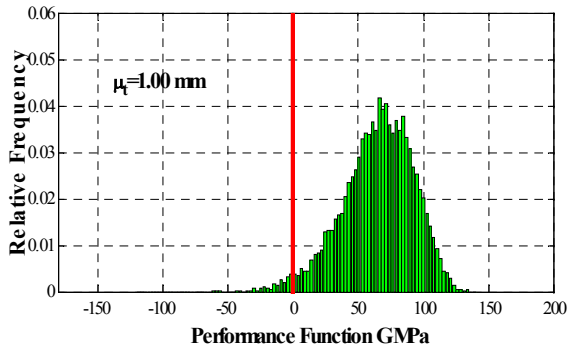


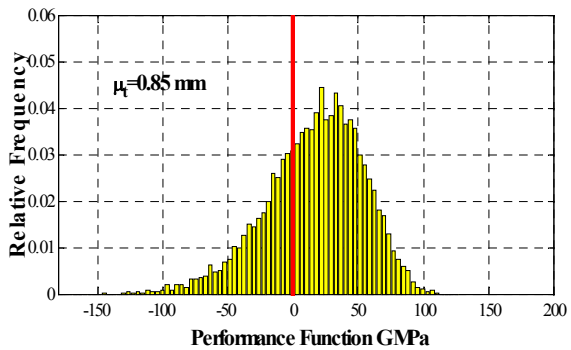




$G = \sigma_{ult} - \sigma_{max}$

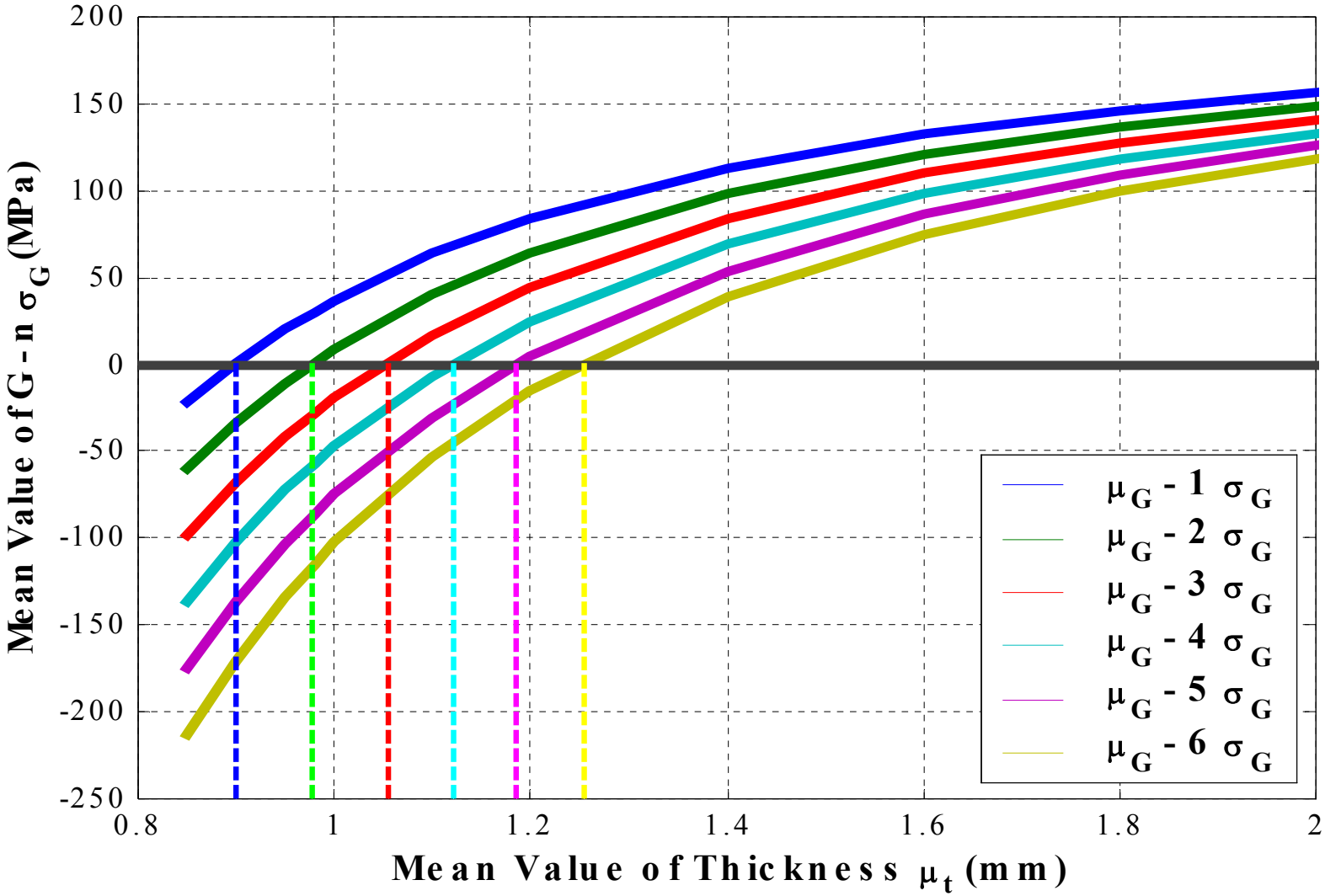




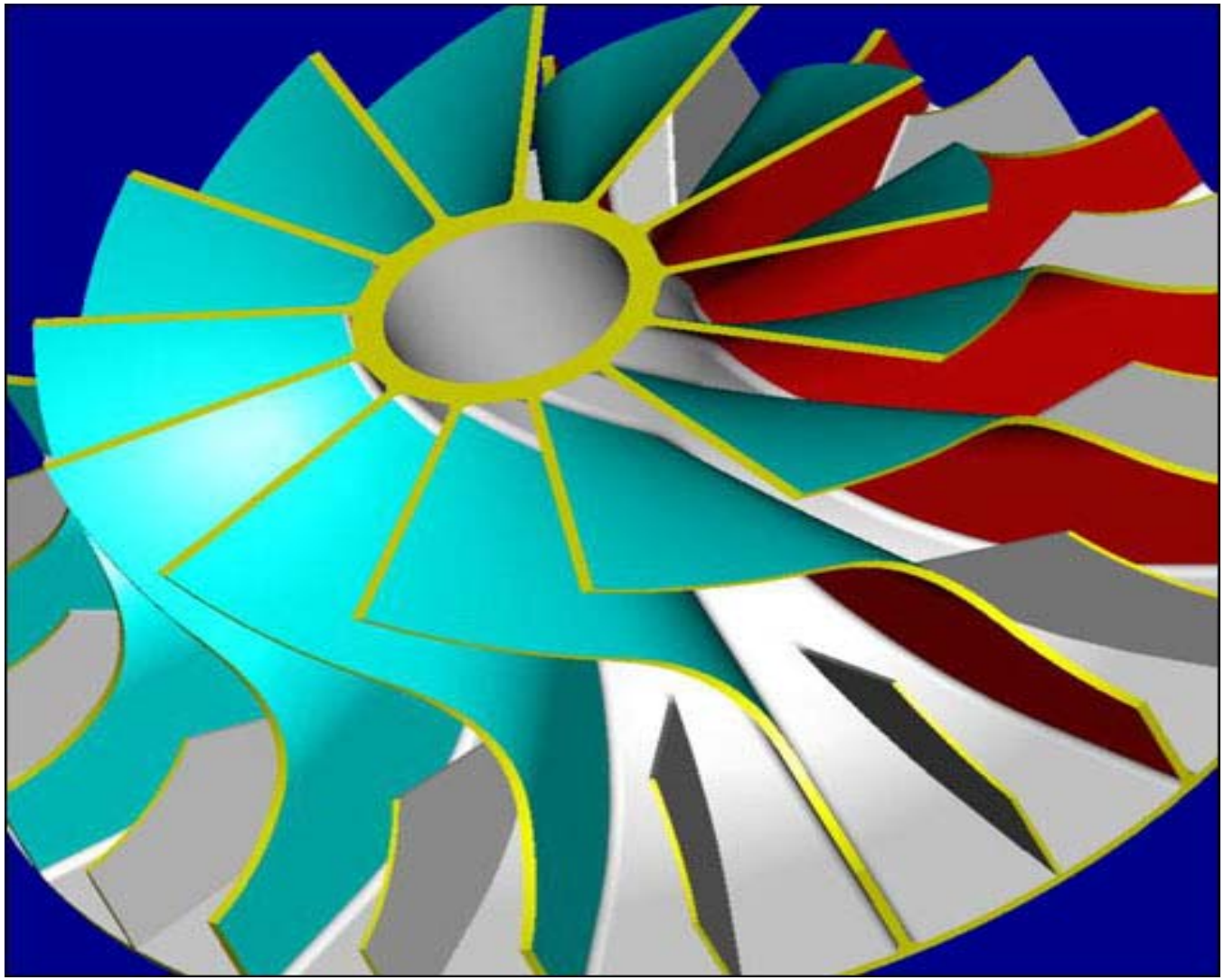


Design Variable selection that meets desired quality criteria

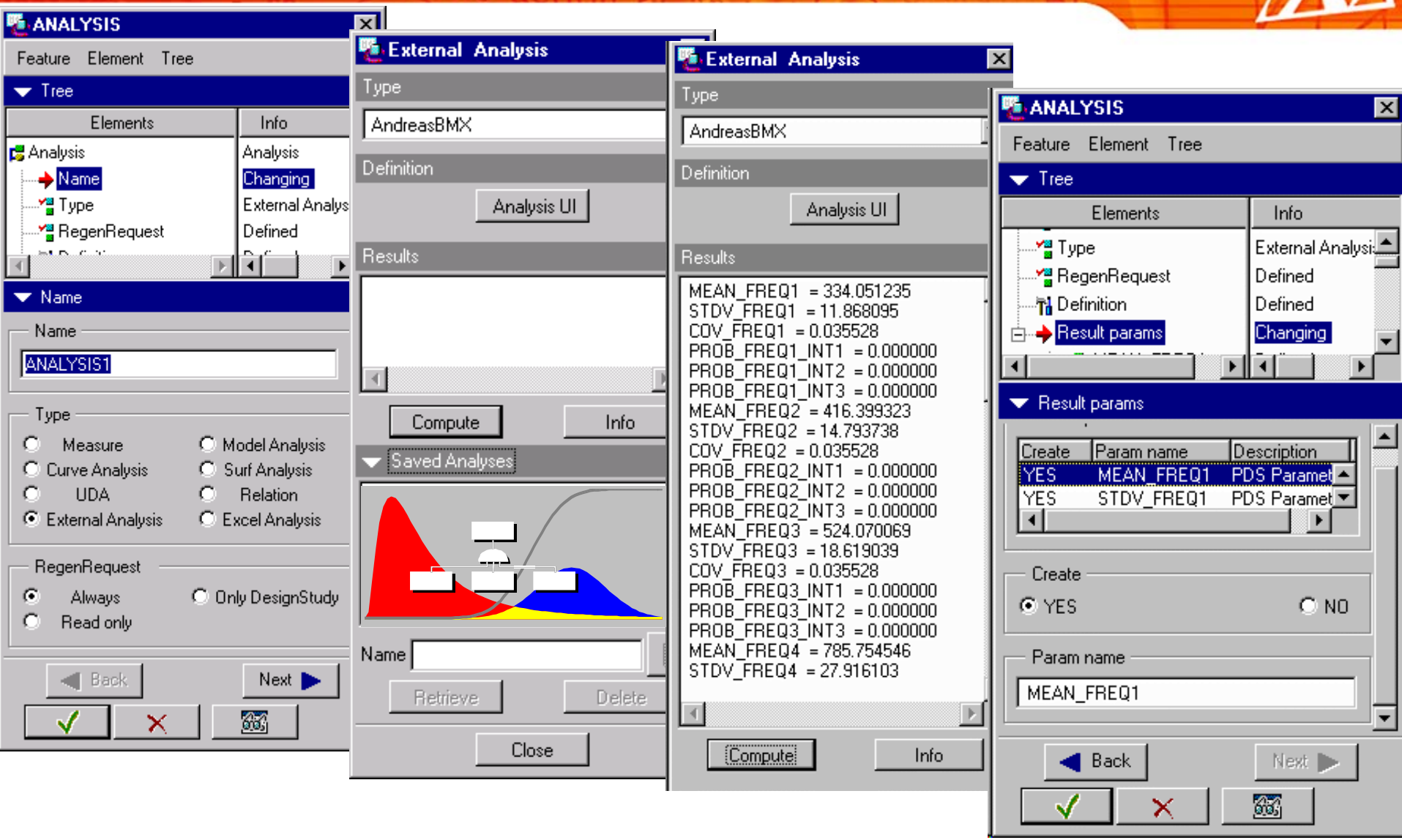
Performance Function $G = \sigma_{ult} - \sigma_{max}$



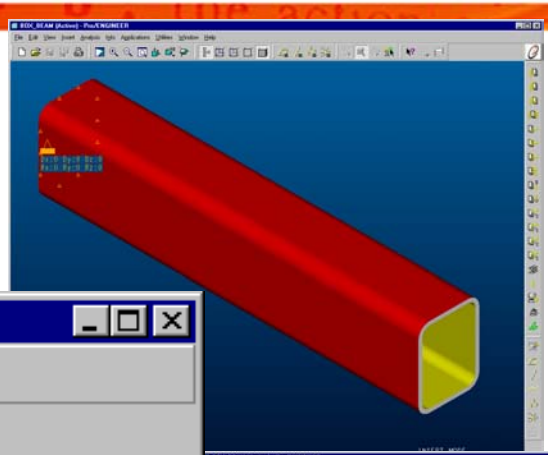
PDS for CAD Design Variables

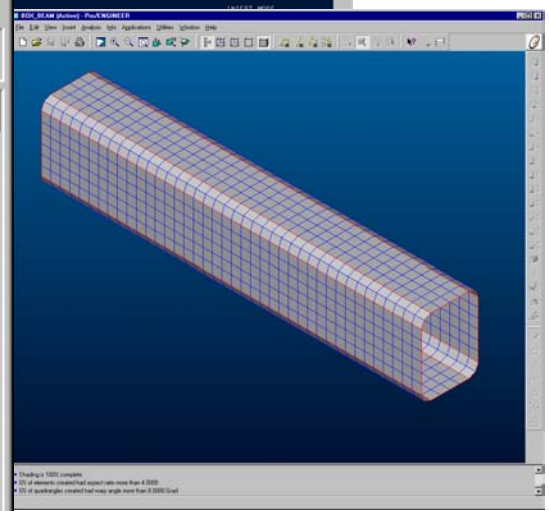


Behavioral Modeling External Analysis – ANSYS_PDS



BMX External Analysis & Optimization Features





Model Tree

File Tree

- BOX_BEAM.PRT
  - RIGHT
  - TOP
  - FRONT
  - PRT_CSYS_DEF
  - Protrusion id 39
  - WEIGHT
  - ANSYS_PDS
  - RELIABILITY_OPTIMIZATION
  - Insert Here

Optimization/Feasibility

File Run Options

Study Type/Name

(•) Optimization ( ) Feasibility

Name: OPTIM1

Goal

Minimize | VOLUME:WEIGHT

Design Constraints

Parameter	Op	Value
PROB_FREQ1_INT1 :ANSYS_PDS	<	0.050000
PROB_FREQ2_INT2 :ANSYS_PDS	<	0.050000

Add... Delete

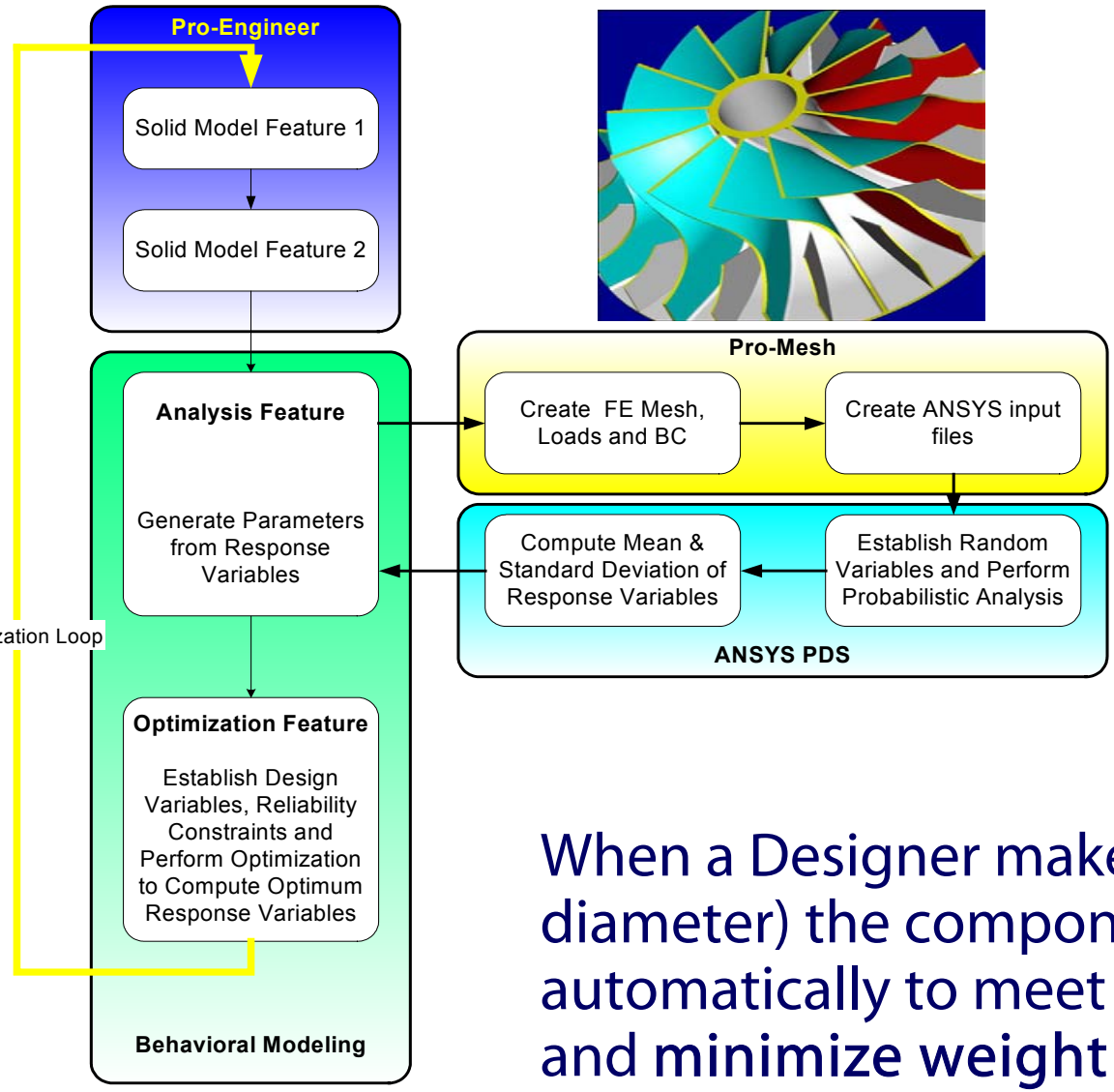
Design Variables

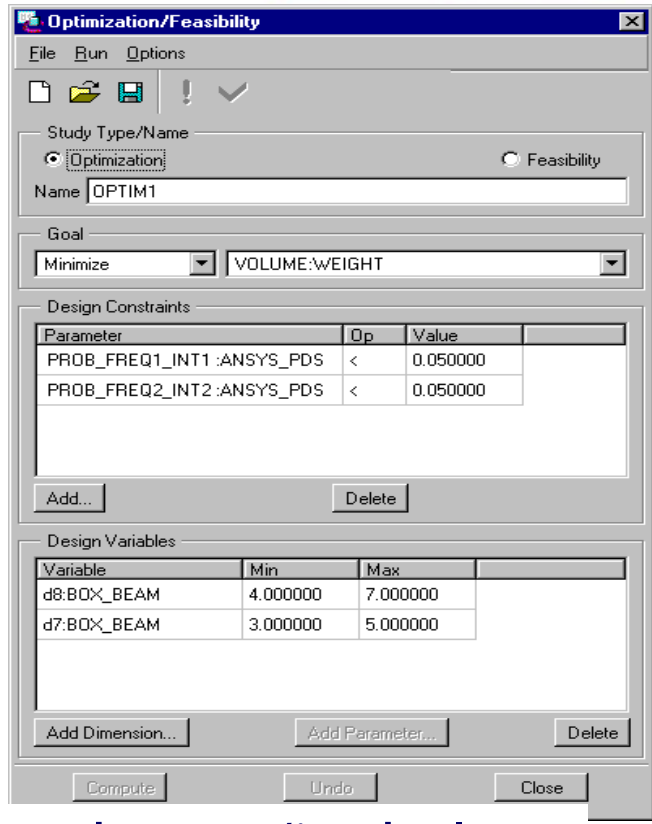
Variable	Min	Max
d8:BOX_BEAM	4.000000	7.000000
d7:BOX_BEAM	3.000000	5.000000

Add Dimension... Add Parameter... Delete

Compute Undo Close

Reliability Based Optimization within Pro/Engineer





When a Designer makes a change (i.e. hole diameter) the component thickness updates automatically to meet desired quality criteria and minimize weight

Conclusions

- Reliability Based Optimization within Pro/Engineer using ANSYS PDS is **available today**
- CAD designs automatically meet **desired quality criteria** and **minimize weight**
- Probabilistic Durability Modeling of Manufacturing Variations coupled with optimization can avoid over-design (deterministic analysis)
- Introduction of Probabilistic analysis in the design process can reduce component weight by 17%